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Control of Broadleaf Weeds in Sunflowers with Desmedipham and Phenmedipham

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CONTROL OF BROADLEAF WEEDS IN SUNFLOWERS WITH DESMEDIPHAM AND PHENMEDIPHAM

BY

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CONTROL OF BROADLEAF WEEDS IN SUNFLOWERS

WITH DESMEDIPHAM AND PHENMEDIPHAM

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Preplant and preemergence herbicides are used currently to control broadleaf weeds in sunflowers (*Helianthus annuus* L.). These herbicides require incorporation practices or early rainfall to be effective, and are most effective for control of grassy weeds but do not control certain broadleaf weed species. Broadleaf weeds such as wild mustard (*Sinapsis arvensis* L.) and redroot pigweed (*Amaranthus retroflexus* L.) are common in sunflower fields. Postemergence herbicides that control these broadleaf weeds are needed in sunflowers.

Phytotoxicity of foliar-applied herbicides is often influenced by rainfall (2, 3, 6, 17, 21, 48, 49). The effect of rainfall on herbicide performance can be influenced by weed species, types and rates of herbicides, quantity of rainfall, and timing of rainfall.

The purpose of this research was to evaluate the postemergence herbicides desmedipham [ethyl *m*-hydroxycarbanilate carbanilate(ester)] and phenmedipham (methyl *m*-hydroxycarbanilate *m*-methylcarbanilate) for broadleaf weed control in sunflowers and to determine their performance under various rainfall conditions.

LITERATURE REVIEW

Desmedipham and phenmedipham are used extensively for postemergence weed control in sugarbeets (Beta vulgaris L.). Desmedipham effectively controls redroot pigweed and both desmedipham and phenmedipham control wild mustard (10, 27, 33, 34, 45). A limited number of studies have been conducted with desmedipham and phenmedipham mixtures in sunflowers (28, 29, 30, 34). These herbicides are toxic to sunflowers when applied at rates commonly used in sugarbeets (33, 34).

Many factors affect the performance of desmedipham and phenmedipham. Increasing the concentration of desmedipham's solvents and adjuvants significantly increased the rate of desmedipham penetration into the sugarbeet foliage (21). Desmedipham penetration was also increased by doubling the spray volume used in application. Split applications of desmedipham provided less sugarbeet injury and equal weed control to a single application of desmedipham only if the split applications were applied at an early date (41). Split applications of desmedipham followed by either phenmedipham or ethofumesate [(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate] gave better weed control and less sugarbeet injury than single applications (16). Another study indicated that a single, well-timed application of desmedipham and phenmedipham was equal to sequential treatments of these herbicides in sugarbeets (19).

High temperatures and high light intensities influence the phytotoxicity of desmedipham, phenmedipham, and combinations of these herbicides (4, 5, 50). Dexter (14) found that these herbicides are more active at high temperatures. Spraying in the afternoon was less injurious to sugarbeets than spraying in the morning when the maximum temperature during the day exceeded 22 C (50). Other studies report that desmedipham treatments are most toxic to sugarbeets when applied in the morning as compared to afternoon and evening applications, even though daytime temperature was highest in the afternoon application (4, 20). The time of day interaction may be explained by the rapid inhibition of photosynthesis in the daytime from light and temperature effects, followed by detoxification processes during the night (4, 5). Thus, better crop tolerance can be expected when spraying desmedipham and phenmedipham in the afternoon and evening.

Broadleaf weeds are best controlled by desmedipham and phenmedipham when treated at an early stage of growth (9, 11, 35, 41, 44, 45). Desmedipham and phenmedipham controlled wild mustard when applied at the two- to four-leaf stage better than at the four- to five-leaf stage (35). Redroot pigweed is best controlled by desmedipham when treated prior to the four-leaf stage (11, 41). Plants which survive desmedipham treatment are less competitive and retreatment is not profitable unless there are many escapes or additional emergence of plants after initial treatment (23).

Wild mustard, redroot pigweed, and sugarbeets were used in a study to examine the selectivity of desmedipham and phenmedipham by evaluating spray retention, absorption, translocation, and metabolism (27). All plant species had reduced CO_2 uptake within 4 h of herbicide application. Photosynthesis in wild mustard was reduced within

4 h of treatment and did not recover within 85 h. Photosynthesis in sugarbeets was slightly affected, but recovered after 24 h. Photosynthesis in redroot pigweed was greatly reduced by both herbicides, although phenmedipham treated plants were able to eventually recover while desmedipham treated plants did not. Within 5 h after herbicide application, redroot pigweed translocated more desmedipham than phenmedipham from the site of absorption and metabolized a large amount of the phenmedipham but little desmedipham. Differences in spray retention and foliar absorption were not believed to cause the selectivity of these herbicides. The greater translocation and decreased metabolism of desmedipham relative to phenmedipham were used to explain the selectivity of desmedipham to redroot pigweed (27).

Sugarbeets stressed for moisture prior to desmedipham treatment had less injury than non-stressed plants (4). Sugarbeets stressed for moisture after desmedipham treatment had less injury than non-stressed plants.

Synergistic and antagonistic interactions have been reported when desmedipham or phenmedipham were applied with other herbicides. Dortenzio and Norris (18) reported decreased control of barnyardgrass (Echinochloa crus-galli (L.) Beauv.) when diclofop {2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid} was tank mixed with desmedipham. Increasing the rate of diclofop could offset this antagonistic interaction. A delay in desmedipham application of 4 days after diclofop treatment resulted in no reduction in barnyardgrass control. Wild oat (Avena fatua L.) control was reduced by tank mixing desmedipham or phenmedipham with diclofop, KK-80 {4-[4-[4-(trifluoromethyl)phenoxy]phenoxy]-2-pentenoic}, sethoxydim {2-[1-(ethoxyimino)-butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}, SD-45328 [alanine,*N*-benzoyl-*N*-(3-chloro-4-fluorophenyl)-1-ethyl ester], or RO-13-8895 {acetone-*o*-[*d*-2-(*p*-[(*a*,*a*,*a*-trifluoro-*p*-tolyl)-oxy]phenoxy] propionyl]oxime} (15, 18, 38, 40, 43). Foxtail (*Setaria* spp.) control has been antagonized when desmedipham was tank mixed with sethoxydim, fluazifop-butyl {(±)-butyl 2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy] phenoxy]propanoate}, or diclofop (31, 32, 46). Generally, broadleaf weed control from desmedipham and phenmedipham was not affected by tank mixing with grass herbicides in these studies. Schroeder and Dexter (42) concluded that wild oats and *Setaria* spp. control with diclofop can be reduced by tank mixing with desmedipham, however, control was not reduced if these herbicides were applied sequentially. Wild mustard, but not redroot pigweed, control was affected synergistically when ethofumesate and desmedipham were tank mixed (21). The synergistic interaction was thought to be caused by an increase in the phytotoxicity of desmedipham through increased foliar penetration.

Rainfall after treatment affects efficacy of postemergence herbicides (2, 3, 6, 17, 21, 48, 49). The rain-free period after treatment required to achieve adequate weed control varies greatly among plant species and herbicide formulation. Behrens and Elakkad (3) reported that 1 mm of simulated rain reduced toxicity of 2,4-D [(2,4-dichlorophenoxy)acetic acid] on wild mustard and redroot pigweed. A simulated rain of 12.5 mm within 8 h after spraying decreased toxicity of desmedipham to sugarbeets (21). Upchurch et al. (49) reported that intense, simulated rainshowers did not reduce 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] effectiveness on woody plants even when applied 5 minutes after herbicide application. They also determined that mixtures of picloram (4-amino-3,5,6-trichloropicolinic acid) and 2,4-D had reduced activity on woody plants as the quantity of simulated rainfall was increased. Simulated rainfall within a few hours of herbicide application caused substantial reductions in wild oat control with difenzoquat (1,2-dimethyl-3,5-diphenyl-1*H*-pyrazolium) and diclofop (48). Doran and Andersen (17) observed reduced bentazon [3-isopropyl-1*H*-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] activity on common cocklebur (*Xanthium pensylvanicum* Wallr.) and velvetleaf (*Abutilon theophrasti* Medic.) with simulated rainfall occurring less than 8 h after treatment in greenhouse studies. Field studies indicated that simulated rainfall less than 24 h after herbicide application reduced bentazon activity on both weed species.

The objectives for this research were to:

1) determine if tank mixtures of desmedipham and phenmedipham are synergistic for control of broadleaf weeds and if these mixtures can be safely used for weed control in sunflowers.
2) evaluate how rainfall quantity and rainfall timing affect the performance of desmedipham and phenmedipham tank mixtures.
3) determine if different soil moisture levels affect the performance of desmedipham and phenmedipham tank mixtures.
4) determine if tank mixtures of sethoxydim and desmedipham plus

phenmedipham can be used without loss in activity for broad spectrum grass and broadleaf weed control.

METHODS AND MATERIALS

Interactive effects of tank mix combinations

Field studies were conducted near Watertown, South Dakota in 1981 and 1982 on a Brookings silty clay loam. Rates of 0, 0.13, 0.28, 0.43, and 0.56 kg ai/ha of both desmedipham and phenmedipham were combined factorially in a randomized complete block design of three replications in 1981. In 1982, rates of 0, 0.28, 0.43, 0.56, and 0.71 kg/ha of each herbicide were combined factorially in a similar design having four replications. The combination of 0 rates of both herbicides constituted the untreated control. Plot size measured 3 by 9.1 m in 1981 and 3 by 12.2 m in 1982. Each plot consisted of three rows 90 cm apart. 'Sokota 6000' sunflowers were planted in 1981 and 'Sokota 4000' were planted in 1982.

Herbicides were applied at the six-leaf stage of the sunflowers each year. Herbicide application in 1981 was made when redroot pigweed was in the four-leaf stage. The density of redroot pigweed was approximately 40 plants/m^2. In 1982, redroot pigweed was in the four-leaf stage of growth and wild mustard was in the four- to five-leaf stage of growth. Weed densities were approximately 100 plants/m^2 for redroot pigweed and 10 plants/m^2 for wild mustard.

EPTC (_S_-ethyl dipropylthiocarbamate) at 3.36 kg/ha was preplant incorporated in 1981 to control annual grasses. In 1982, a late post-emergence treatment of sethoxydim at 0.28 kg/ha plus crop oil concentrate[1] at 1.25% (v/v) was used to control annual grasses. A bicycle-mounted sprayer was used to apply all herbicides in 187 L/ha of water at 245 kPa.

Visual evaluations of weed control were made approximately 2 and 4 weeks after treatment. Crop injury ratings were made 5 days after herbicide application. Three subsamples of the broadleaf weeds present in 625-cm^2 areas were taken from each plot 2 and 4 weeks after treatment in 1981, and 3 weeks after treatment in 1982. Plants were dried at 40 C and dry weights recorded. Sunflower heights were taken approximately 12 days apart beginning 2 weeks after herbicides were applied. Sunflowers were harvested with a small plot combine in 1981 and by hand in 1982.

Analysis of variance was performed on all data for each year. For each dependent variable, independent variables having a significant F value at the .05 level and no interaction were averaged over levels of the other independent variable and regression analysis performed on the replicated averages. Observations expressed on a percentage scale were given weighted regression when needed. Dependent variables having a significant interaction between independent variables were given stepwise multiple regression and response surface analysis (7, 22, 39). The type and magnitude of interaction occurring between levels of the two herbicides was determined using Colby's method (8). The Statistical Analysis System (SAS) package was used to perform the

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[1]Atplus, ICI Americas, Inc.

statistical analysis on this and the following experiments.

Effect of rainfall on herbicide performance

Field studies were conducted near Watertown, South Dakota in 1981 and 1982. Equivalent mixtures of desmedipham and phenmedipham were used to apply 0.86 and 1.12 kg/ha of these herbicides in each year of the amount of rainfall study and in the 1982 time interval study. The time interval study in 1981 had only the 0.86 kg/ha rate of the herbicide mixture. Herbicide rates and the various rainfall treatments were factorially arranged in randomized complete block designs with four replications. Plot size measured 3 by 4.6 m with three rows of sunflowers planted 90 cm apart. 'Sokota 6000' sunflowers were planted in 1981 and 'Sokota 4000' were planted in 1982.

EPTC at 3.36 kg/ha was preplant incorporated in 1981 to control annual grasses. In 1982, a late postemergence treatment of sethoxydim at 0.28 kg/ha plus crop oil concentrate at 1.25% (v/v) was used to control annual grasses. A bicycle-mounted sprayer was used to apply all herbicides in 187 L/ha of water at 245 kPa.

Rainfall was simulated over each plot with an oscillating 80° flat-fan nozzle positioned 2.7 m above ground level delivering water over a 2.4- by 3-m area. A pressure of 68 kPa supplied 6.9 L/min of water, which was equivalent to 6.4 cm of rainfall in 1 h. Heavy plastic enclosed the rectangular metal structure to prevent wind effects on rainfall pattern. Herbicide treatments followed by rainfall simulation were usually applied from late evening through mid-morning hours to reduce temperature, light, and wind fluctuations.

Rainfall was applied immediately after herbicide application in quantities of 0, 0.25, 2.54, 5.08, and 12.7 mm in each year to study the amount necessary to reduce herbicide performance. In 1981, rainfall was simulated at intervals of 0.02, 0.25, 0.5, 1, 4, and 8 h after herbicide application to study the rain-free period necessary to prevent loss in herbicide performance. A control plot was sprayed with herbicide that had no rainfall applied until 3 days later when natural rainfall occurred. In 1982, time intervals of 0.02, 0.5, 1, 4, 8, 16, and 32 h between herbicide application and rainfall simulation were used. No control plot was included in the 1982 experiment since longer time intervals were used. A rain of 12.7 mm during 12 minutes was applied in all time interval treatments to simulate a typical summer thundershower.

Analysis of variance was performed on all data for each year. Data were averaged across the two herbicide rates of 0.86 and 1.12 kg/ha and were transformed to percent of maximum values for each year. The 0 mm rainfall constituted the maximum for the amount of rainfall experiment, with the 3 day treatment in 1981 and 32 h treatment in 1982 being the maximums for the time interval experiment. This enabled the two years' data to be combined when no interaction between years was detected. Regression analysis and non-linear regression techniques were used to fit appropriate curves to the data. Sunflower height data were analyzed with the Waller-Duncan k-ratio T test with k-ratio = 100 ($P = 0.05$).

Effect of different moisture levels on herbicide performance

Rainfall amounts of 0, 12.7, and 25.4 mm were simulated as described previously on sunflower plots 12 and 11 days prior to herbicide application, respectively, in 1981 and 1982. Tank mixtures of equivalent rates of desmedipham and phenmedipham were applied in 1981 at the combined rate of 0.56, 0.84, and 1.12 kg/ha and in 1982 at the combined rate of 0, 0.84, 1.12, and 1.40 kg/ha. In 1981, the three rainfall amounts and three herbicide rates were factorially combined; in addition, a single treatment with no rain and no herbicide was included as a weedy check. A randomized complete block design with 4 replications was used in 1981. In 1982, treatments were factorially arranged in a randomized complete block design with 4 replications.

Herbicides were applied to sunflowers which were 45 cm tall in 1981 and sunflowers which were 30 cm tall in 1982. Redroot pigweed was 15 to 30 cm tall and wild mustard was 30 to 60 cm tall in 1981. In 1982, herbicide application was made when redroot pigweed was 12 to 18 cm tall and wild mustard was 30 to 45 cm tall. In 1982, soil probes were taken to a depth of 15 cm at the time of herbicide application from each of the three moisture regimes to quantify gravimetrically the change in soil moisture. A 1.9 cm diameter probe was used to take the samples. Each probe was divided into two samples, 0 to 5 cm and 5 to 15 cm. Samples were oven dried at 100 C and g H_2O/g soil calculated. Visual evaluations of crop injury and weed control were made each year. Broadleaf weeds were harvested from two 625-cm^2 areas per plot two weeks after herbicide treatment and dry weight determined.

Results were analyzed statistically and the means were compared with the Waller-Duncan k-ratio T test with k-ratio = 100 (P = 0.05).

Interaction in broad spectrum weed control

Field experiments at Redfield and Watertown were conducted in 1982 to study the feasibility of tank mixing sethoxydim and a commercial mixture of desmedipham and phenmedipham.[2] Sethoxydim at 0, 0.28, and 0.43 kg/ha plus crop oil concentrate at 1.25% (v/v) was combined factorially with 0, 0.84, 1.12, and 1.40 kg/ha of Betamix. Treatments were arranged in a randomized complete block design having four replications at Redfield and three replications at Watertown. Plot size was 3 by 12.2 m at Redfield and 3 by 9.1 m at Watertown. Each plot consisted of three rows 90 cm apart. 'Sokota 4000' sunflowers were planted at each location.

Herbicides were applied at the six- to eight-leaf stage of the sunflowers at each location. At Redfield, herbicides were applied when *Setaria* spp. was 2.5- to 7.5-cm tall and wild buckwheat (*Polygonum convolvulus* L.) plants were 2.5- to 10-cm tall. At the Watertown location, *Setaria* spp. was 5- to 10-cm tall, redroot pigweed plants were 5- to 7.5-cm tall, and wild mustard plants were 10- to 15-cm tall.

Visual evaluations of crop injury and weed control were made at each location. Three subsamples of the grass and broadleaf weeds present in 625-cm^2 areas were taken from each plot 4 weeks after treatment

[2]In this study, the commercial name Betamix is used hereafter to refer to equal mixtures of desmedipham and phenmedipham.

from the Redfield location and 3 weeks after treatment from the Watertown location. Plant samples were dried at 40 C and dry weights recorded. Sunflower heights were measured throughout the growing season at both locations. A small plot combine was used to harvest the entire plot for sunflower yield at Redfield. Sunflowers were harvested manually from the middle row in each plot at Watertown.

Analysis of variance was performed on all data for each location. Significant interactions between rates of sethoxydim and rates of Betamix were analyzed with Colby's method (8). Means of herbicide rates were separated with the Waller-Duncan k-ratio T test with k-ratio = 100 ($P = 0.05$).

RESULTS AND DISCUSSION

Interactive effects of tank mix combinations

A significant interaction occurred between rates of desmedipham and phenmedipham for wild mustard control in 1982. The multiple regression equation fitted to the data accounted for 98% of the variation in wild mustard control (Figure 1). The response surface plotted from this equation illustrates that desmedipham at 0.71 kg/ha gave complete (100%) control of wild mustard, while the same rate of phenmedipham gave only 67% control. The higher coefficient for the desmedipham term in the equation indicates that increasing the rate of desmedipham gave better control than increasing the rate of phenmedipham. At the 0 rate of phenmedipham, rates of desmedipham act in a linear fashion, as shown by the straight line along the desmedipham axis. As the rate of phenmedipham is increased, the response to desmedipham becomes quadratic. Complete control was obtained when 0.71 kg/ha of phenmedipham was combined with approximately 0.35 kg/ha of desmedipham. The smaller rectangles in the upper left corner of the graph indicate that the interaction between desmedipham and phenmedipham is not the same as in other portions of the graph. The nature of the interaction was determined using Colby's method. Generally, the interaction was synergistic as shown in Table 1. As the rate of phenmedipham was held constant, increasing rates of desmedipham decreased the magnitude of synergism. As the rate of desmedipham was held constant, increasing rates of phenmedipham increased the magnitude of synergism, except at the 0.71 kg/ha rate of desmedipham. Addition of

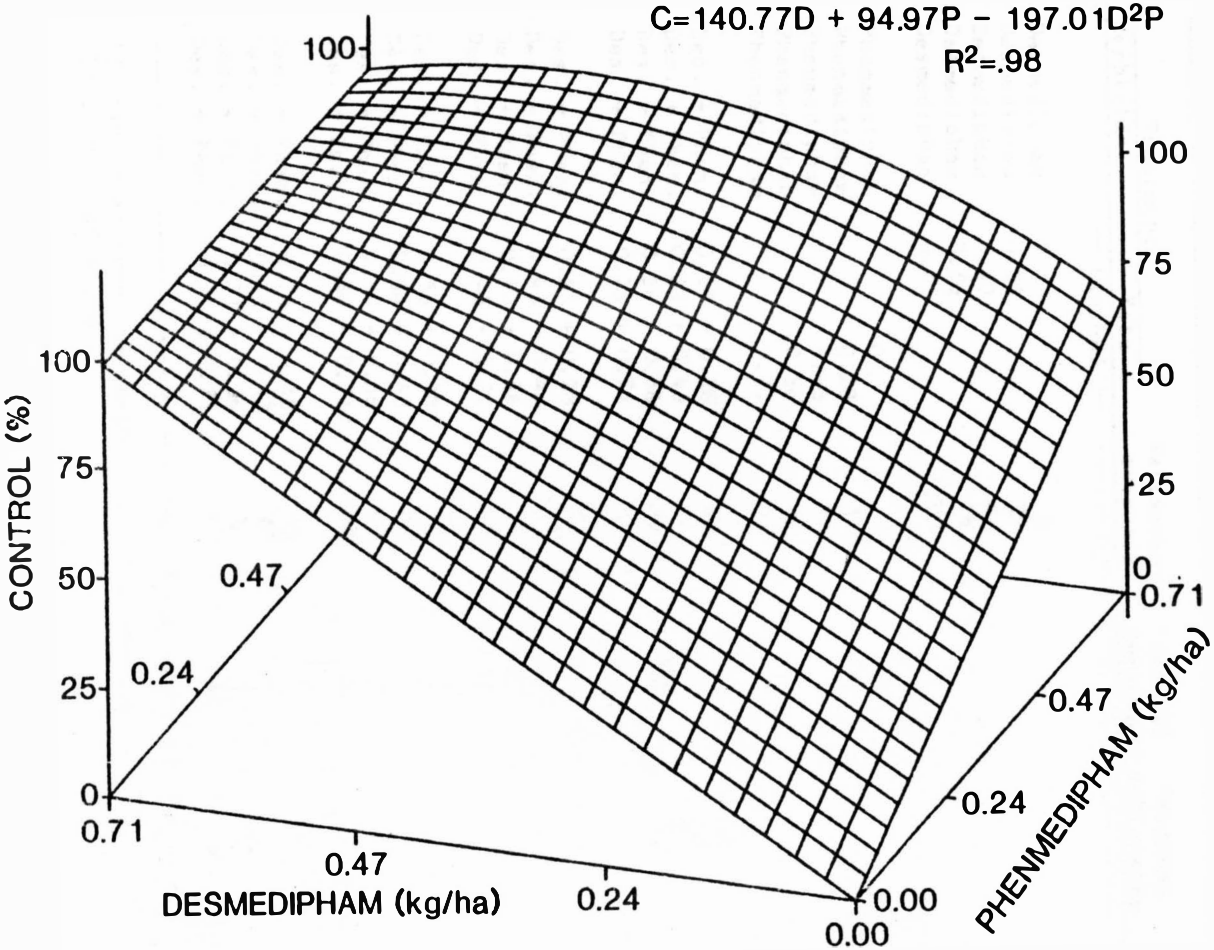

Figure 1. Interaction of various rates of desmedipham and phenmedipham on visual control of wild mustard in 1982. In the equation, C = percent control, D = rate of desmedipham, and P = rate of phenmedipham.

Table 1. The type of interaction with various rates of desmedipham and phenmedipham on visual control of wild mustard.

Treatment: Herbicide	Treatment: Rate	Extrapolated response[a]	Expected response[b]	Response difference	Interaction
	-- (kg/ha) --	------------	(%)	--------------	
Desmedipham	0	0			
Desmedipham	0.28	39			
Desmedipham	0.43	61			
Desmedipham	0.56	79			
Desmedipham	0.71	100			
Phenmedipham	0	0			
Phenmedipham	0.28	27			
Phenmedipham	0.43	41			
Phenmedipham	0.56	53			
Phenmedipham	0.71	67			
Des. + Phen.	0.28 + 0.28	62	55	+7	Synergism
Des. + Phen.	0.28 + 0.43	74	64	+10	Synergism
Des. + Phen.	0.28 + 0.56	84	61	+13	Synergism
Des. + Phen.	0.28 + 0.71	96	80	+16	Synergism
Des. + Phen.	0.43 + 0.28	77	72	+5	Synergism
Des. + Phen.	0.43 + 0.43	86	77	+9	Synergism
Des. + Phen.	0.43 + 0.56	93	82	+11	Synergism
Des. + Phen.	0.43 + 0.71	100	87	+13	Synergism
Des. + Phen.	0.56 + 0.28	88	85	+3	Synergism
Des. + Phen.	0.56 + 0.43	93	88	+5	Synergism
Des. + Phen.	0.56 + 0.56	97	90	+7	Synergism
Des. + Phen.	0.56 + 0.71	100	93	+7	Synergism
Des. + Phen.	0.71 + 0.28	99	100	-1	Antagonism
Des. + Phen.	0.71 + 0.43	98	100	-2	Antagonism
Des. + Phen.	0.71 + 0.56	98	100	-2	Antagonism
Des. + Phen.	0.71 + 0.71	97	100	-3	Antagonism

[a]Extrapolated from the response surface equation, $C = 140.77D + 97.97P - 197.01D^2P$, $R^2 = .98$.

[b]Expected response of herbicide combinations based on Colby's calculation (8).

phenmedipham to 0.71 kg/ha desmedipham resulted in slight antagonism which is represented by the small rectangles in the upper left corner of Figure 1. Colby's test indicates the type and magnitude of interaction, but does not provide for assigning statistical significance to the results (36, 37). In this research, Colby's test was useful for identifying the nature of the interaction evident in the overall texture of the response surface illustrated in Figure 1.

Redroot pigweed control increased linearly with increasing rate of desmedipham in both years (Figure 2). Higher rates of desmedipham are generally used to control redroot pigweed than those used in this research. Therefore, inadequate control was observed at the highest rate. Rates of phenmedipham did not significantly affect redroot pigweed control in 1981, and had only a minor influence on redroot pigweed control in 1982 (data not shown). Phenmedipham is not known to control this weed.

The higher slope for 1981 as compared to the slope for 1982 indicates a greater degree of effectiveness of each rate increase of desmedipham on redroot pigweed control (Figure 2). The differences in control between the 2 years of our study are further substantiated by the evaluations of redroot pigweed control made 4 weeks after applications in both years, giving the same results as the evaluations made 2 weeks after application. The difference in control between the 2 years may be attributed to the EPTC used in 1981. EPTC application has been shown to alter cuticle development on expanding plant leaves and this condition may lead to greater sensitivity to foliar-applied herbicides

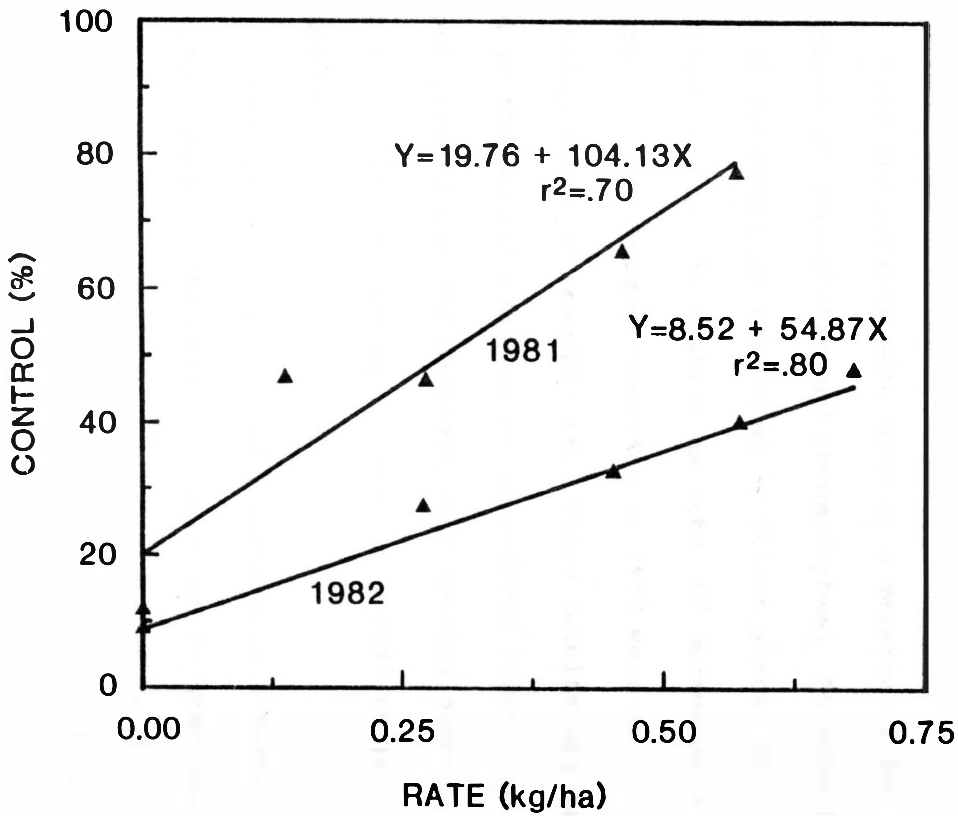

Figure 2. Visual evaluations of redroot pigweed control with rates of desmedipham averaged across phenmedipham rates in 1981 and 1982. The 0 rate of desmedipham represents the average control of all rates of phenmedipham. Plotted points are the means of four replications. Regressions were conducted on individual data values.

(24, 25, 26). A tendency for increased broadleaf weed control has been observed previously when a foliar application of desmedipham is made following a preplant incorporated treatment of EPTC (10). Furthermore, Dawson (9) reported the preconditioning effect of cycloate (S-ethyl N-ethylthiocyclohexanecarbamate) on broadleaf weeds in sugarbeets to later applications of phenmedipham.

Weed dry weights were used as a measure of the broadleaf control from rates of desmedipham and phenmedipham. No significance between rates of phenmedipham was found in either years' data. Dry weights decreased in a linear fashion as rates of desmedipham increased in 1981 (Figure 3). Dry weights recorded in 1982 were not influenced by increasing rates of desmedipham. These results are similar to those noted in the visual evaluations of redroot pigweed control. In 1982, redroot pigweed was the dominant weed species present, and the poor control of this species was evident in visual evaluations and in weed dry weights.

Symptoms of injury to sunflowers were a burning or necrosis of the outer edges of the leaves. These injury symptoms have been reported in other studies with these herbicides in sunflowers (33, 46, 47). Leaves emerging after herbicide application were not affected. Generally, symptoms disappeared within 3 weeks of treatment.

Crop injury ratings were nearly identical for each herbicide in both years. A significant interaction between levels of desmedipham and phenmedipham occurred in both years, according to the analysis of variance. Stepwise multiple regression revealed that the interaction

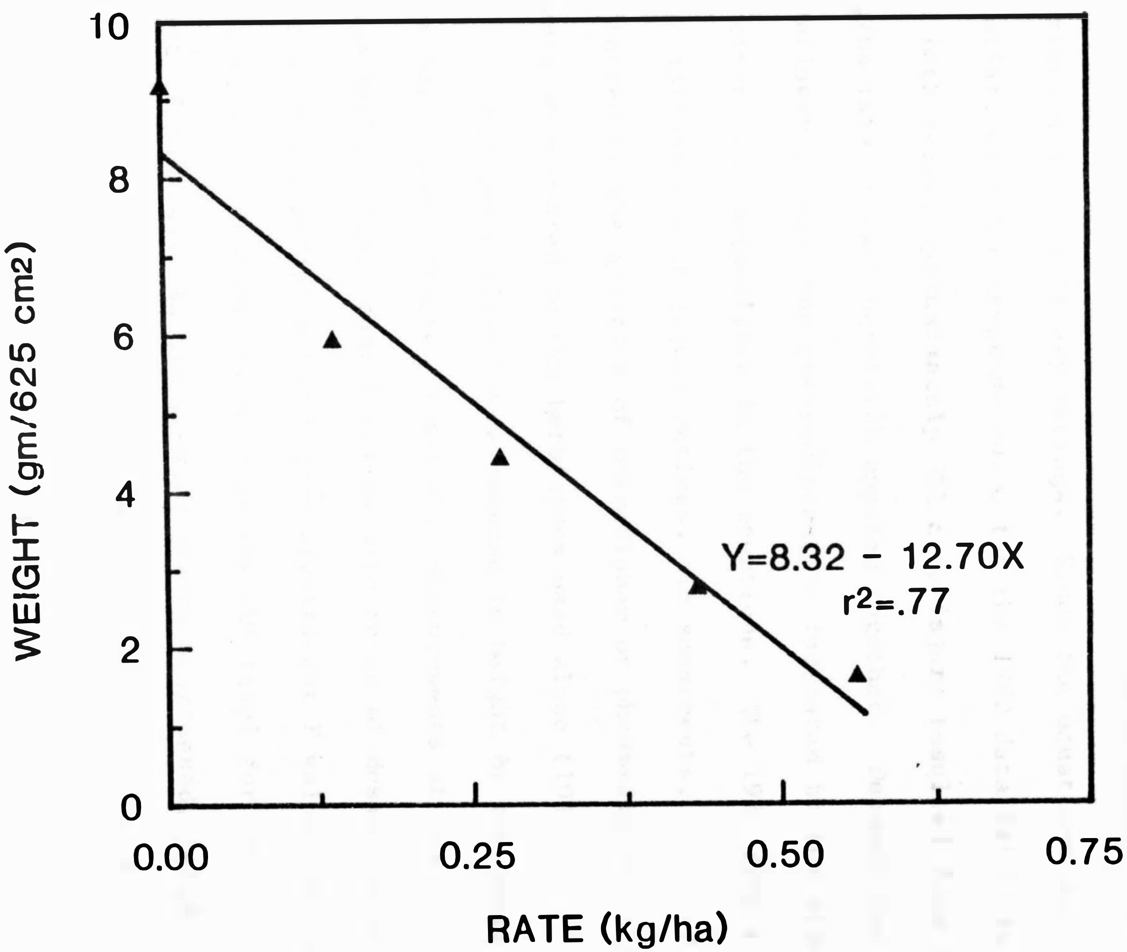

Figure 3. The dry weight of weeds as affected by various rates of desmedipham in 1981. The 0 rate of desmedipham represents the average weight of weeds for all rates of phenmedipham. Plotted points are the means of four replications. Regression was conducted on individual data values.

was best fitted by a linear response of the levels of both herbicides. The interaction equation for the 1981 data was Y = 42.18 x desmedipham + 21.19 x phenmedipham, with R^2 =.94. In 1982, a similar equation of Y = 36.25 x desmedipham + 24.94 x phenmedipham explained 98% of the variation in crop injury ratings. Since the equations are quite similar, only the response curve for the 1982 data is shown (Figure 4). In both years, approximately 35% crop injury resulted from the 0.56 kg/ha rate of each herbicide applied together. Desmedipham caused more sunflower injury than phenmedipham, as indicated by the higher coefficients for desmedipham in the equations. The 1981 EPTC treatment did not influence crop injury ratings. In sugarbeets, injury has not been affected by the addition of desmedipham or phenmedipham to EPTC treatments as compared to the herbicides used alone (10).

Sunflower plants were reduced in height by the application of the herbicides (Figures 5 and 6). Measurements at the first three dates gave highly significant F values with rates of desmedipham (Figure 5). Rates of phenmedipham had highly significant F values at the first two dates, and a probability of F at the .06 level for the July 30 measurement (Figure 6). As the growing season progressed, height differences were less obvious, and the equations follow this trend. Heights were similar at the final measurement, and the F values along with the linear or quadratic coefficients were insignificant for both herbicides. Desmedipham tended to decrease height more than phenmedipham, especially at the July 7 and July 19 measurements, as indicated by the higher intercepts and slopes for desmedipham. The height reductions

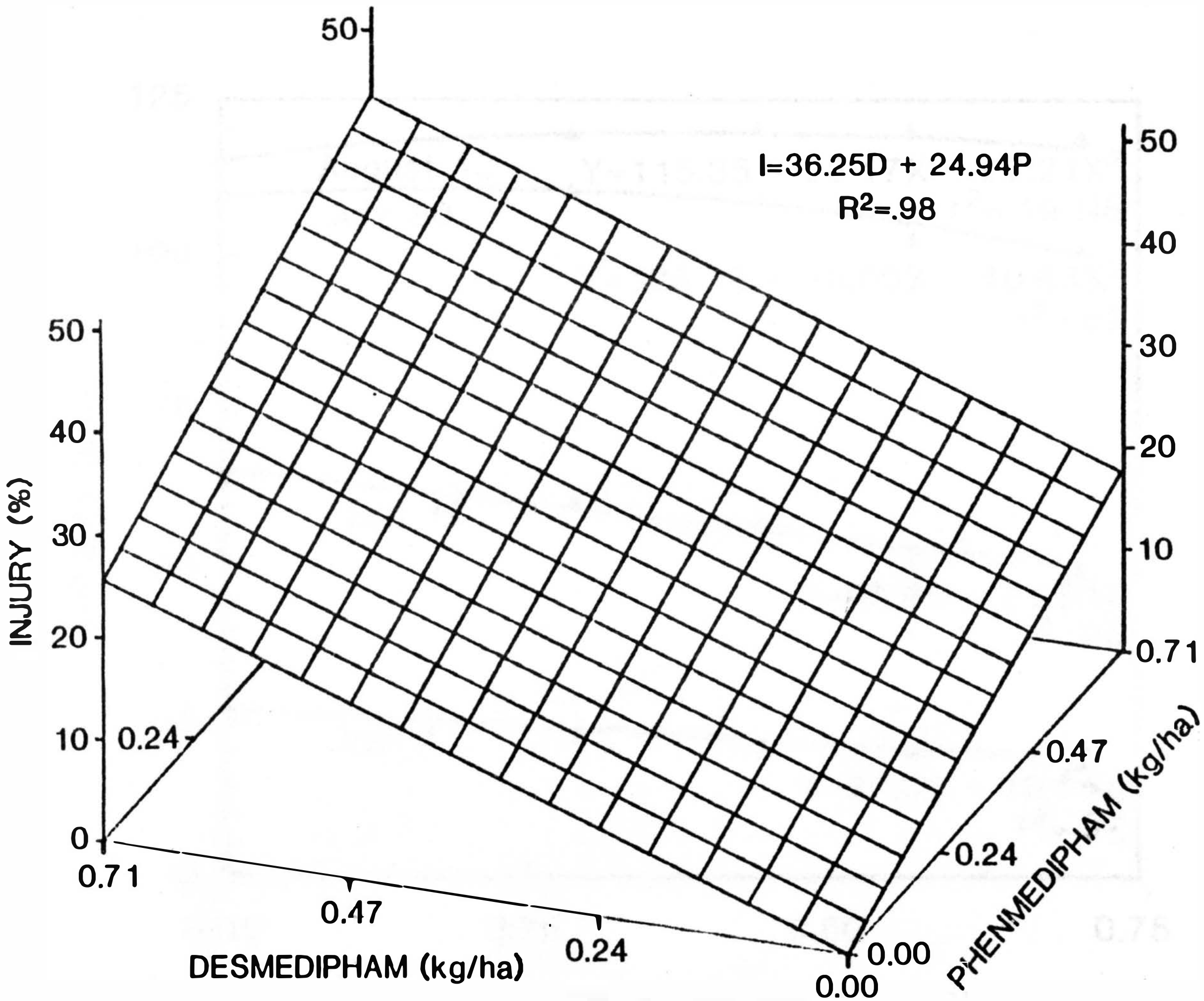

Figure 4. Interaction of various rates of desmedipham and phenmedipham on sunflower injury in 1982. In the equation, I = percent injury, D = rate of desmedipham, and P = rate of phenmedipham.

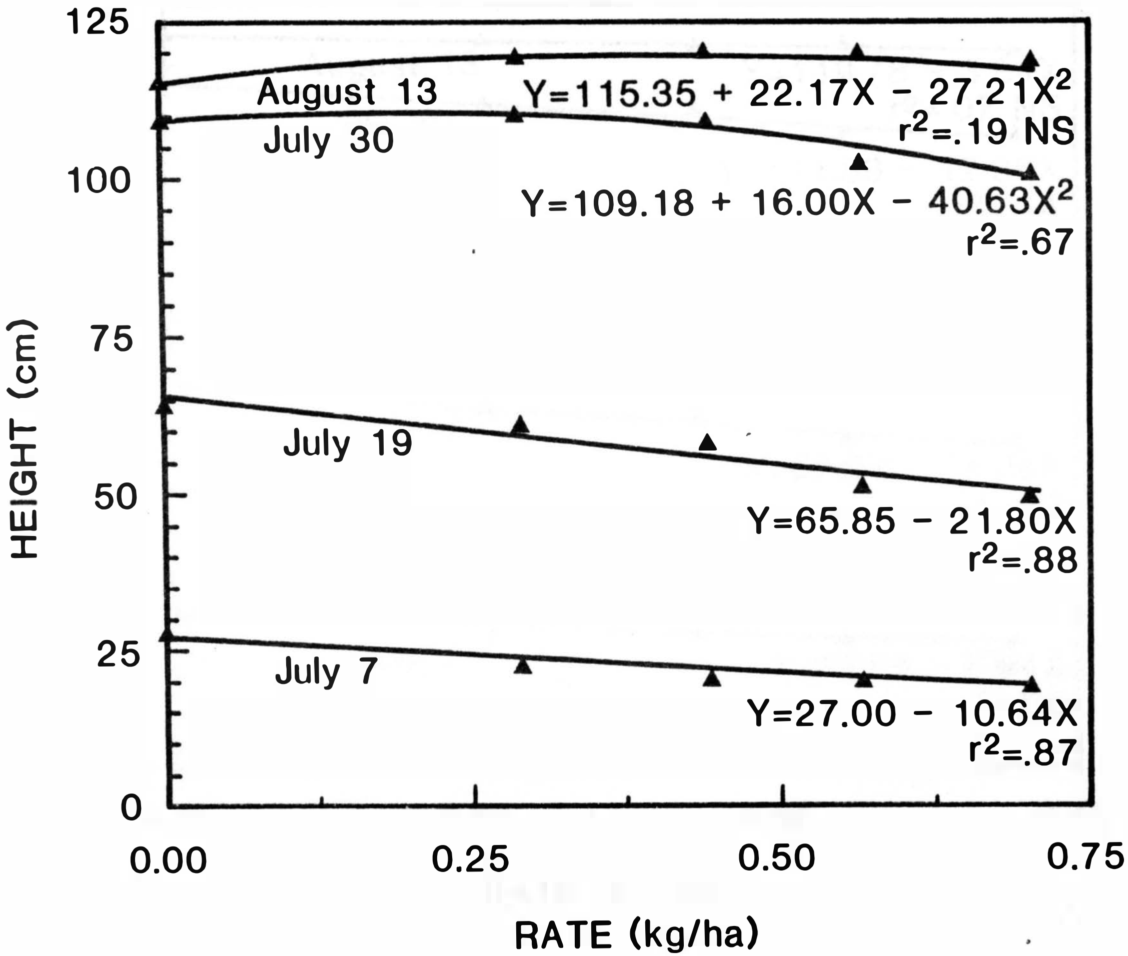

Figure 5. Effect of various rates of desmedipham on sunflower heights during the 1982 growing season. Measurements were on July 7, July 19, July 30, and August 13. The 0 rate of desmedipham represents the average height of all rates of phenmedipham. Plotted points are the means of four replications. Regressions were conducted on individual data values.

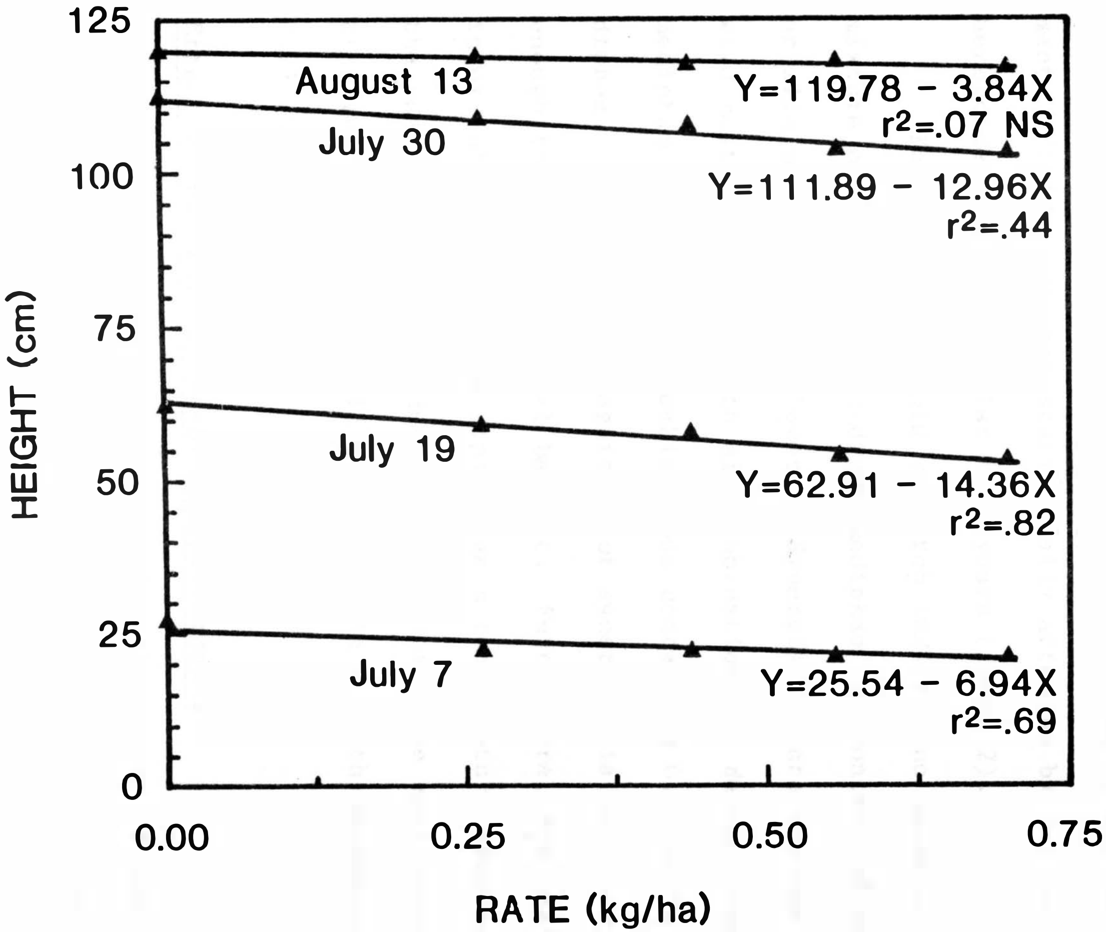

Figure 6. Effect of various rates of phenmedipham on sunflower heights during the 1982 growing season. Measurements were on July 7, July 19, July 30, and August 13. The 0 rate of phenmedipham represents the average height of all rates of desmedipham. Plotted points are the means of four replications. Regressions were conducted on individual data values.

are similar to the visual observations of injury discussed previously. Reductions in sunflower height and the incidence of leaf injury early in the growing season did not affect the overall growth and maturity of the crop. Date of flowering was not affected by any herbicide treatment. Yields were not statistically affected by any rate of either herbicide and were similar both years (Table 2).

The results of this research indicate no clear advantage to a mixture of desmedipham and phenmedipham for control of redroot pigweed or wild mustard in sunflowers. Synergistic interactions occurred for wild mustard control with all combinations of desmedipham and phenmedipham except those combinations containing 0.71 kg/ha of desmedipham. However, the magnitude of synergism is probably not great enough to be of practical benefit. Furthermore, the effects on crop injury of the compounds applied as a tank-mixture were additive. Since the cost of the herbicides is about equal, the most economical application for controlling wild mustard would be with desmedipham alone at 0.71 kg/ha.

Effect of rainfall on herbicide performance

Rainfall quantity. Increasing the amount of immediate rainfall after application decreased the control of redroot pigweed by the tank mixture of desmedipham and phenmedipham (Figure 7). A significant interaction occurred between the two years' data, therefore years were analyzed separately. Linear-over-linear inverse polynomial equations describe the control of redroot pigweed. Percent of maximum is equal to the control obtained from the untreated check, which had herbicide

Table 2. Sunflower yields as affected by various rate combinations of desmedipham and phenmedipham.

Treatment			Yield[a]	
Herbicide	Rate		1981	1982
	---(kg/ha)---		------(kg/ha)------	
Des. + Phen.	0[b]	0	607[c]	905
Des. + Phen.	0	0.13	806	---[d]
Des. + Phen.	0	0.28	793	820
Des. + Phen.	0	0.43	712	720
Des. + Phen.	0	0.56	843	754
Des. + Phen.	0	0.71	---	713
Des. + Phen.	0.13	0	764	---
Des. + Phen.	0.13	0.13	788	---
Des. + Phen.	0.13	0.28	922	---
Des. + Phen.	0.13	0.43	813	---
Des. + Phen.	0.13	0.56	847	---
Des. + Phen.	0.28	0	752	878
Des. + Phen.	0.28	0.13	824	---
Des. + Phen.	0.28	0.28	837	889
Des. + Phen.	0.28	0.43	601	877
Des. + Phen.	0.28	0.56	743	868
Des. + Phen.	0.28	0.71	---	974
Des. + Phen.	0.43	0	563	941
Des. + Phen.	0.43	0.13	764	---
Des. + Phen.	0.43	0.28	842	915
Des. + Phen.	0.43	0.43	750	940
Des. + Phen.	0.43	0.56	766	892
Des. + Phen.	0.43	0.71	---	852
Des. + Phen.	0.56	0	764	860
Des. + Phen.	0.56	0.13	803	---
Des. + Phen.	0.56	0.28	727	945
Des. + Phen.	0.56	0.43	832	860
Des. + Phen.	0.56	0.56	861	997
Des. + Phen.	0.56	0.71	---	915
Des. + Phen.	0.71	0	---	926
Des. + Phen.	0.71	0.28	---	958
Des. + Phen.	0.71	0.43	---	777
Des. + Phen.	0.71	0.56	---	963
Des. + Phen.	0.71	0.71	---	819
Coefficient of variability (%)			22.1	14.5

[a]Differences not detected at the 5% probability level of F in the analysis of variance.

[b]The 0 + 0 rate of desmedipham + phenmedipham is the untreated check.

[c]Data are treatment means of sunflower seed yields.

[d]This rate combination was not included in the particular year's study.

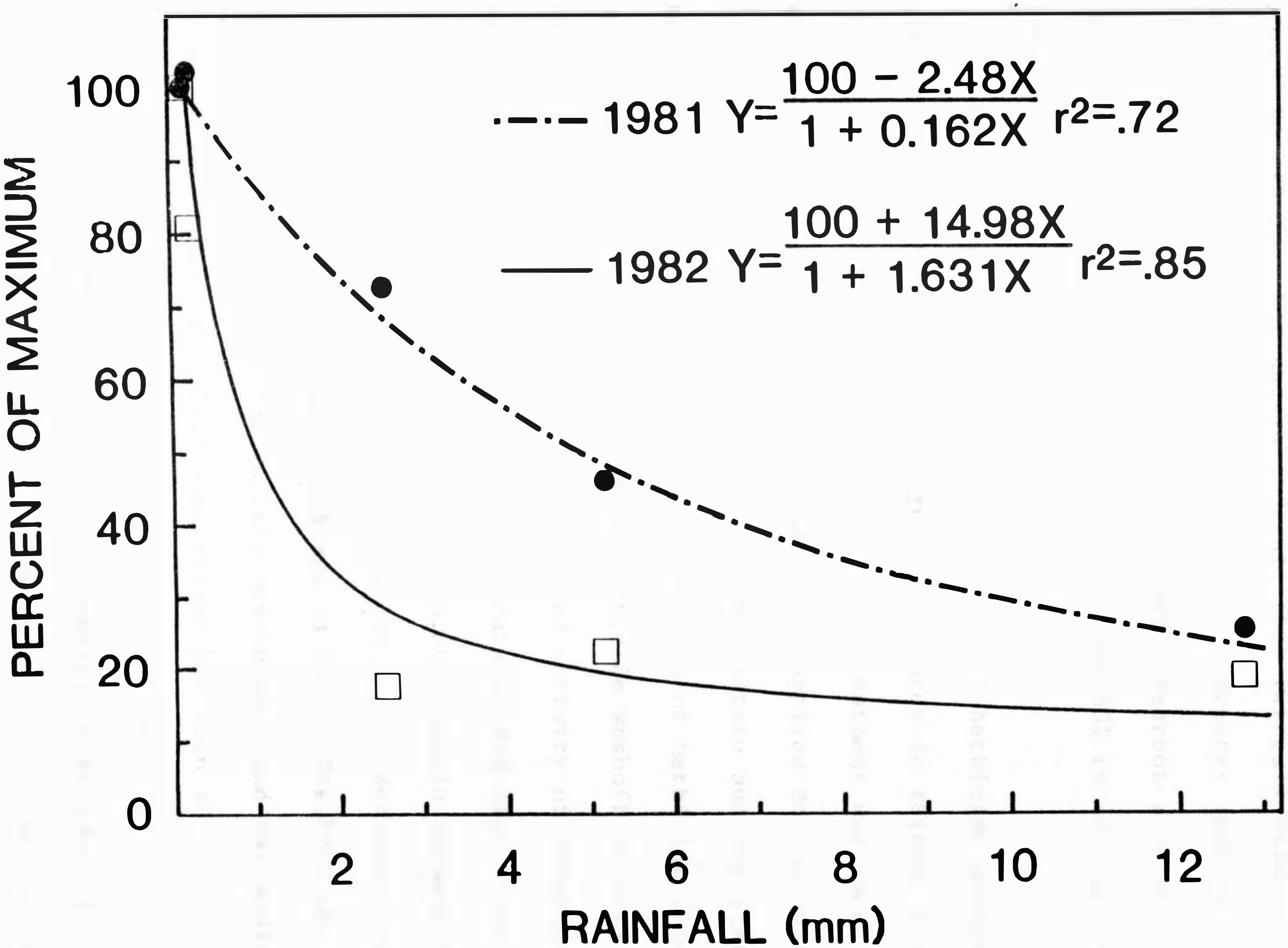

Figure 7. Percent of maximum control of redroot pigweed in 1981 and 1982 as affected by different quantities of simulated rainfall applied immediately after desmedipham and phenmedipham application. Percent of maximum mean values are plotted for each rainfall quantity. Regressions were performed on data values from each replication in each year.

application but no rainfall treatment. In both years, control of redroot pigweed decreased sharply as the amount of rain was increased from 0 to 2.5 mm. The curves indicate that rainfall reduced control of redroot pigweed more in 1982 than in 1981. Greater redroot pigweed control was observed in 1981 than in 1982. Redroot pigweed control for the untreated check, or maximum control, was 60% in 1981 and 44% in 1982.

Differences in temperature, light, and herbicide penetration between 1981 and 1982 may explain the differences in redroot pigweed control. In 1981, the temperature during treatment was about 12 C higher than in 1982. Treatments were also applied during daytime hours in 1981, but not in 1982. The warmer temperature and application in daylight in 1981 may have increased the rate of herbicide absorption and permitted greater resistance to herbicide washoff by rain. Previous research has indicated increased activity of desmedipham and phenmedipham when applied at high temperatures and high light intensities (4, 5, 50). Differences in the plant cuticle between the two years may have affected herbicide penetration and decreased herbicide washoff on the redroot pigweed foliage in 1981. The EPTC application in 1981 may have altered the cuticle development and may explain the differences in control. EPTC application has been shown to alter cuticle development on expanding plant leaves and this condition may lead to greater sensitivity to foliar-applied herbicides (24, 25, 26). Enhanced redroot pigweed control by desmedipham and phenmedipham has occurred following EPTC application (1).

Wild mustard control significantly decreased as rainfall quantity increased (Figure 8). The no rainfall treatment gave 88% control of wild mustard. Approximately 12% wild mustard control was lost with each 0.5 mm increment of rainfall up to 2 mm. Wild mustard control was only 50% of maximum when 2 mm of rainfall was applied immediately after herbicide application. Rainfall amounts greater than 2 mm only slightly decreased control of wild mustard.

These herbicides caused leaf necrosis and height reduction to sunflowers but did not reduce stand. These injury symptoms on sunflowers have been reported in other studies (1, 33, 46, 47). In this study, injury was decreased when increasing amounts of rainfall were applied (Figure 8). A large drop in injury occurred when up to 1 mm was applied, and injury slowly decreased when more than 2 mm of rain was applied. The untreated plot gave 32% injury.

Sunflower plants receiving rain after treatment with herbicide were taller throughout the growing season than treated plants which received no rainfall (Table 3). Simulated rainfall of 0.25 mm effectively washed off enough herbicide to significantly increase sunflower height over plots that had no rainfall applied. Additional rainfall increased plant height 2 weeks but not 5 weeks after treatment. Injury effects were not as obvious later in the growing season as the plants recovered from initial injury.

These results indicate that a sudden rainfall of 1 mm can appreciably diminish the control of redroot pigweed and wild mustard by desmedipham and phenmedipham. Minute quantities of rainfall

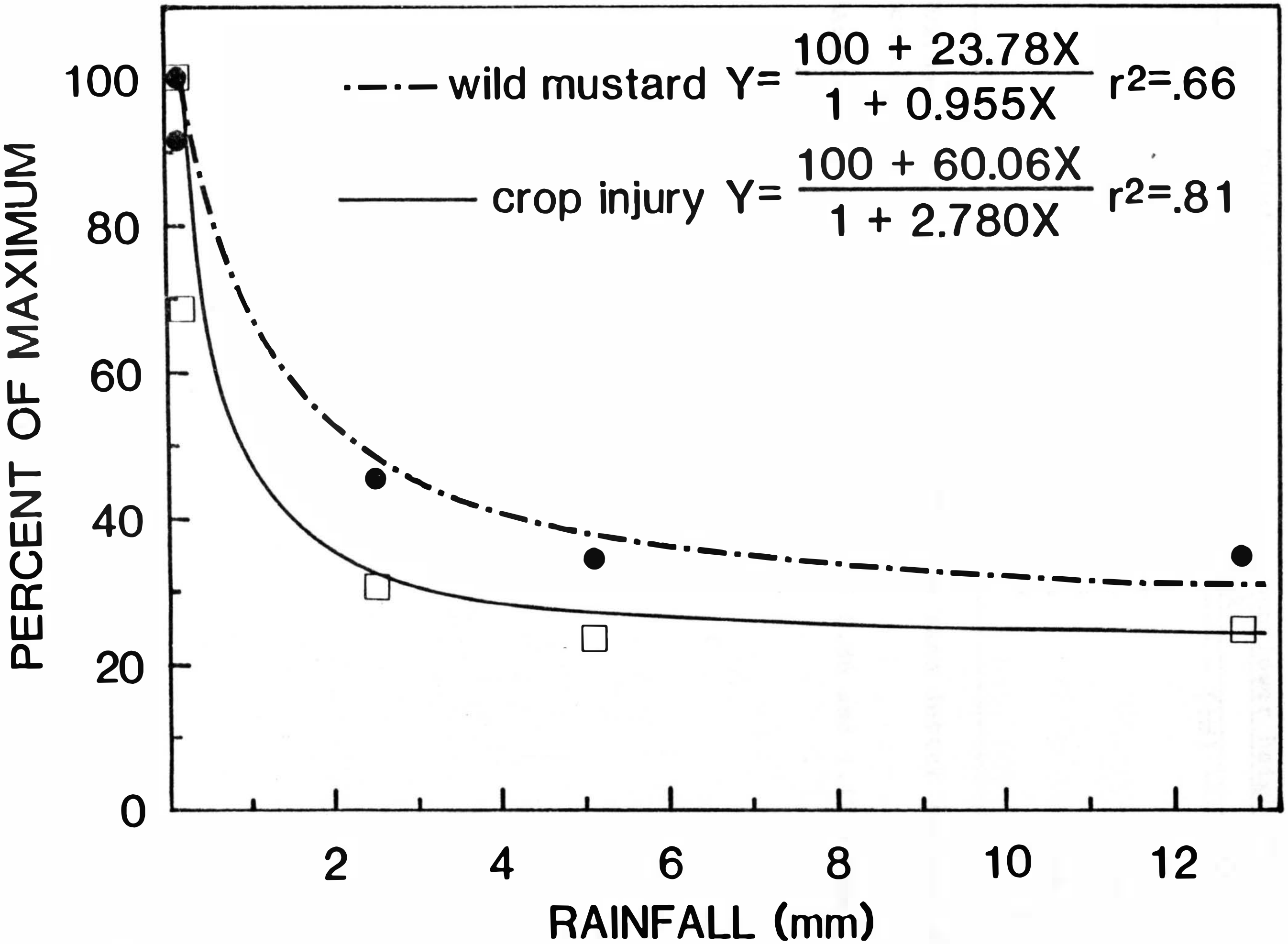

Figure 8. Effect of rainfall quantity immediately after herbicide application on wild mustard control and sunflower injury with mixtures of desmedipham and phenmedipham. Percent of maximum mean values are plotted for each rainfall quantity. Regressions were performed on data values from each replication in each year.

Table 3. Effect of various quantities of simulated rainfall on sunflower height 2 and 5 weeks after application of a tank mix of desmedipham and phenmedipham in 1982.

Rainfall amount	Sunflower height[a,b]	
	2 weeks	5 weeks
- (mm) -	---------- (cm) ----------	
0	21 c	98 b
0.25	27 b	116 a
2.54	31 a	120 a
5.08	31 a	114 a
12.7	31 a	113 a

[a]Values within a column followed by the same letter are not significantly different at the 5% level.

[b]Averaged across the herbicide rates of 0.86 and 1.12 kg/ha.

immediately after herbicide application effectively reduced the injury on sunflowers.

Time intervals. The various time intervals between herbicide application and 12.7 mm of simulated rainfall affected the control of redroot pigweed and wild mustard with desmedipham and phenmedipham mixtures in 1981 and 1982 (Figure 9). No interactions occurred between years, therefore, data were combined into a single regression for each parameter. Actual control numbers were 61% and 93% for redroot pigweed and wild mustard. The control of redroot pigweed increased as the length of time between herbicide application and simulated rainfall increased. However, the improvement in redroot pigweed control occurred at a slow rate as the time interval increased. Only half of the maximum control was achieved when rain occurred 5 h after herbicide application. Redroot pigweed apparently requires a long absorption period with desmedipham and phenmedipham. A rain-free period of about 18 h or more was necessary to achieve 85% or more of the maximum control. This length of time without rain would be difficult to predict prior to herbicide application. Wild mustard control did not require as long a rain-free period as did redroot pigweed. The natural log equation describing wild mustard control indicated that rainfall soon after herbicide application did not affect wild mustard as dramatically as it did redroot pigweed. A sharp increase in the percent of maximum control, shown by the linear phase of the curve, was observed within the first hour of herbicide application. Two hours of rain-free conditions allowed desmedipham and phenmedipham to express

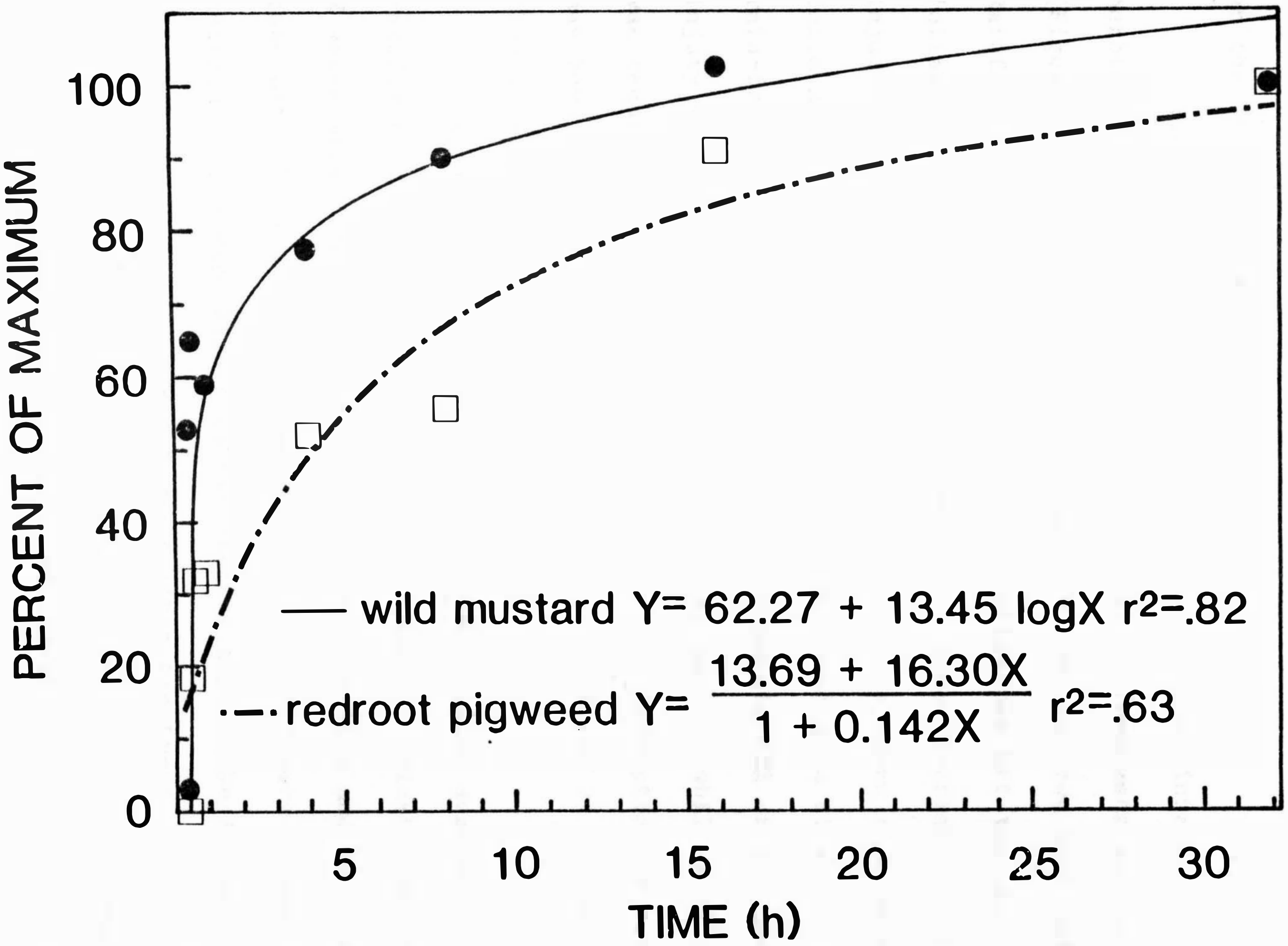

Figure 9. The effect of various time intervals between herbicide application and rainfall treatment on wild mustard and redroot pigweed control with desmedipham and phenmedipham mixtures. Means of the percent of maximum control are shown for each rainfall interval. Regressions were performed on data values from each replication in each year.

approximately 70% of its maximum control of wild mustard. A rain-free period of approximately 6 h or more appears to permit adequate performance of the herbicides on wild mustard. Maximum control was achieved at the 16 h interval.

Sunflower injury was increased as the time interval between herbicide application and simulated rainfall treatment was increased (Figure 10). The maximum injury was 31% over the two year period. Rainfall was effective in washing the herbicides off the sunflower foliage and reducing crop injury. Only a minor portion of the crop injury was prevented if rain occurred within a short time after herbicide application. Additional injury occurred at a slow rate when the rain-free period was lengthened. Approximately 85% of the maximum injury was predicted for a 18 h rain-free period, while a 32 h period was required to achieve 100% phytotoxicity. Absorption of desmedipham has been reported to increase throughout the first 24 h after application in sugarbeets (21).

Sunflower height data from the 1982 growing season supports the results of the visual injury ratings (Table 4). Plants measured 2 weeks after treatment were shorter with the 16 h and 32 h intervals than with the 4 h or less time intervals. Sunflowers in the 32 h interval plots were significantly shorter than those in the 0.02 h interval plots when measured 5 weeks after treatment. The shortest sunflowers were observed at the 32 h interval at all four measurements taken in 1982, however, late-season measurements contained no significant differences in either year (data not shown). Intervals of 16 to

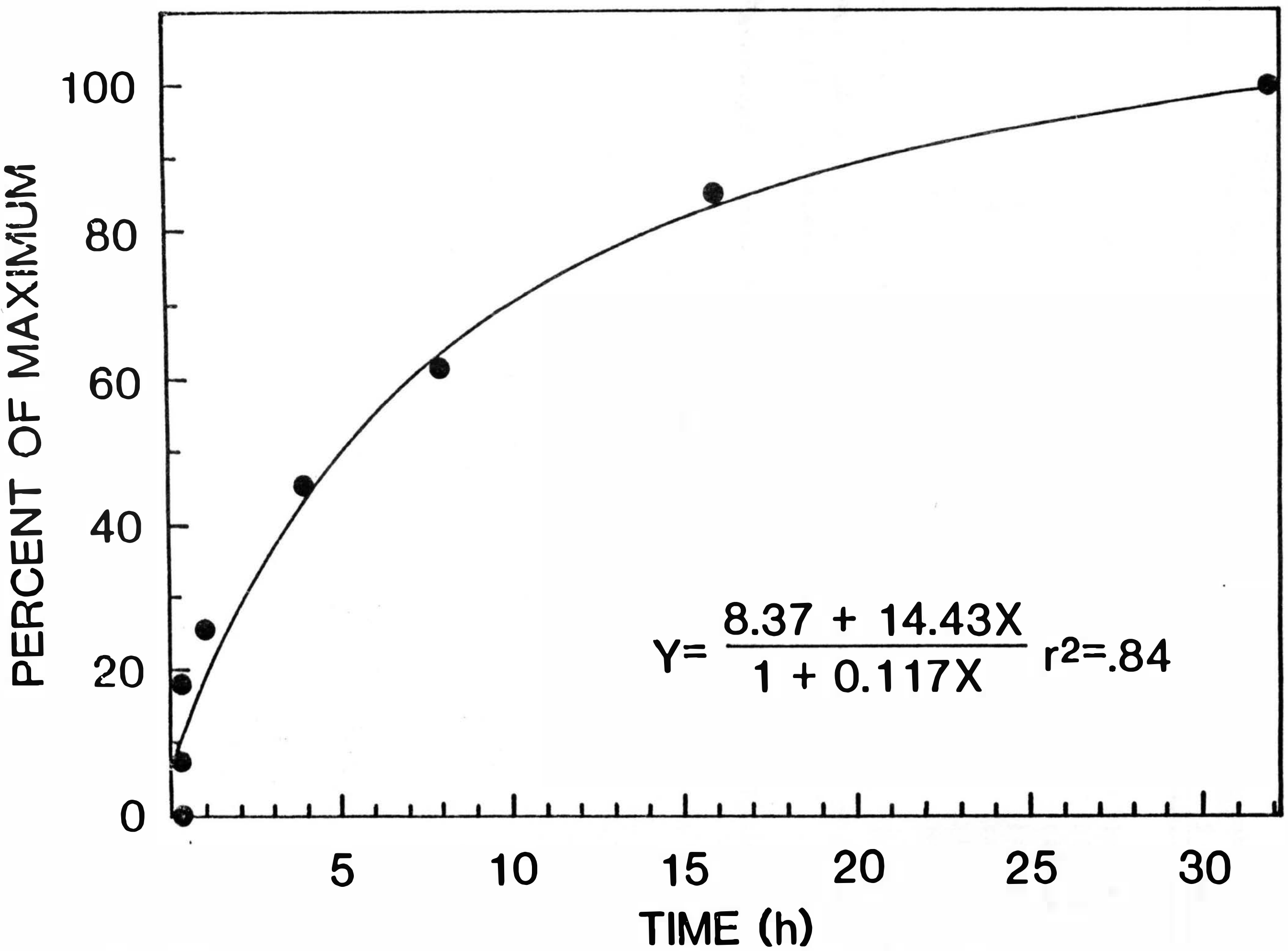

Figure 10. The effect of various time intervals between herbicide application and rainfall treatment on sunflower injury with desmedipham and phenmedipham mixtures. Means of the percent of maximum injury are shown for each rainfall interval. Regression was performed on data values from each replication in each year.

Table 4. Effect of various time intervals between herbicide application and 12.7 mm of simulated rainfall on sunflower height 2 and 5 weeks after treatment in 1982.

Interval between treatment and rainfall	Sunflower height[ab]	
	2 weeks	5 weeks
----- (h) ------	---------- (cm)	----------
0.02	30 a	118 a
0.5	28 a	115 ab
1	30 a	116 ab
4	28 a	117 ab
8	27 ab	111 ab
16	24 b	111 ab
32	23 b	103 b

[a]Values within a column followed by the same letter are not significantly different at the 5% level.

[b]Averaged across the herbicide rates of 0.86 and 1.12 kg/ha.

32 h prior to rain were necessary for herbicidal activity to significantly affect the height of the sunflowers.

These results indicate that rainfall within a short time after desmedipham and phenmedipham application reduces redroot pigweed control, wild mustard control, and crop injury effects. Rainfall within 5 h of herbicide application severely reduces redroot pigweed control. Redroot pigweed requires a relatively long rain-free period of about 18 h to exhibit 85% of the maximum control attainable in these studies. Wild mustard control was mostly affected by rainfall within the first few h after herbicide application. A rain-free period of only 6 h was effective in controlling wild mustard. Crop injury from these herbicides was greatly reduced when rainfall occurred soon after herbicide application. Approximately 18 h without rain after treatment permitted 85% of the maximum injury on sunflowers. Herbicide toxicity on sunflower height was expressed when rainfall was delayed at least 16 h after treatment.

Effect of different moisture levels on herbicide performance

No significant differences in gravimetric soil moisture or depth of moisture penetration were found between the various moisture levels. However, plots receiving 12.7 and 25.4 mm rainfall tended to have higher soil moisture than plots receiving no additional water. These samples were taken 11 days after the water was applied, which may have been too long to obtain soil moisture differences.

Rainfall levels were averaged across herbicide rates to reveal the general effect of these moisture levels on herbicide performance

(Table 5). Weed sizes were much larger in all plots at the time of herbicide application than that considered best for optimum performance of desmedipham and phenmedipham. Subjecting sunflowers to various moisture levels prior to desmedipham and phenmedipham application resulted in no significant differences in visual evaluations of redroot pigweed and wild mustard or weed dry weights in 1981 or 1982. The application of 25.4 mm of rain appeared to slightly decrease the weed control in relation to no additional rainfall. This was due to larger weeds present in the plots receiving rainfall as compared to the plots without rainfall. There were no significant differences between crop injury ratings among the different moisture levels. More injury to sunflowers was detected in 1981 than in 1982 because of earlier evaluation after herbicide treatment.

Rates of desmedipham plus phenmedipham averaged across moisture levels gave significant differences in redroot pigweed control, wild mustard control, and crop injury ratings in 1981 and 1982 (Table 6). Increasing the herbicide rate gave better weed control but also more crop injury. Dry weights of weeds were greater in plots receiving no herbicide than those treated with herbicide, indicating that desmedipham and phenmedipham were effective in reducing the weed growth. These results are similar to those obtained in the previous studies.

Results of this study indicate that applying 0, 12.7, or 25.4 mm rains 11 to 12 days prior to desmedipham plus phenmedipham application cause no differences in weed control, weed dry weight, and crop injury. The various moisture levels applied were not reflected in the

Table 5. Effect of various moisture regimes on desmedipham and phenmedipham performance when averaged across herbicide rates in 1981 and 1982.

Rainfall applied prior to treatment[a]	Redroot pigweed control[b]		Wild mustard control[b]		Weed dry weight[b]		Sunflower injury[b]	
	1981	1982	1981	1982	1981	1982	1981	1982
------ (mm) ------	---------- (%) ----------				--- (g) ---		--- (%) ---	
0	69 a	32 a	83 a	64 a	5.6 a	2.8 a	31 a	11 a
12.7	63 a	31 a	77 a	63 a	5.7 a	4.5 a	26 a	15 a
25.4	64 a	30 a	78 a	60 a	7.1 a	4.8 a	27 a	14 a

[a]Rainfall applied 12 and 11 days prior to herbicide treatment, respectively, in 1981 and 1982.

[b]Values within a column followed by the same letter are not significantly different at the 5% level.

Table 6. Effect of various rates of desmedipham and phenmedipham averaged across moisture regimes on weed control, weed dry weight, and sunflower injury in 1981 and 1982.

Rainfall applied prior to treatment	Redroot pigweed control[a]		Wild mustard control[a]		Weed dry weight[a]		Sunflower injury[a]	
	1981	1982	1981	1982	1981	1982	1981	1982
----- (kg/ha) ----	(%)				--- (g) ---		--- (%) ---	
0[b]	0 b	0 d	0 b	0 c	16.7 a	4.9 a	0 c	0 d
0.56	62 a	--	76 a	--	5.2 b	---	18 b	--
0.84	67 a	24 c	80 a	53 b	6.3 b	4.8 a	30 a	9 c
1.12	67 a	32 b	81 a	65 a	7.0 b	4.0 a	36 a	14 b
1.40	--[c]	38 a	--	69 a	---	3.4 a	--	17 a

[a]Values within a column followed by the same letter are not significantly different at the 5% level.

[b]The 0 rate of herbicide in 1981 reflects only the 0 mm rainfall treatment.

[c]This herbicide rate was not included in the particular year's experiment.

gravimetric measurement of soil moisture at the time of herbicide application. Better control of weeds was achieved as the rate of herbicide was increased. Better growing conditions through increased moisture levels did not appear to enhance the activity of these herbicides on broadleaf weeds because weed size increased as a result of the additional moisture. Small weed size is critical for good results with desmedipham and phenmedipham.

Interaction in broad spectrum weed control

Combinations of sethoxydim with Betamix gave less control of *Setaria* spp. than when sethoxydim was used alone at the Redfield location (Table 7). Betamix rates alone gave some control of *Setaria* spp. According to Colby's calculation, the addition of the broadleaf herbicide to sethoxydim antagonized the control of *Setaria* spp. (Table 8). Antagonism was most prominant when sethoxydim was combined with 0.84 kg/ha of the broadleaf herbicides.

At the Watertown location, tank mixtures of the grass and broadleaf herbicides gave equal or better control of *Setaria* spp. than when either herbicide was used alone (Table 7). Combining Betamix with 0.43 kg/ha of sethoxydim gave significantly greater control than when this rate of sethoxydim was applied alone. Little control was apparent from the broadleaf herbicides, but when added to the grass herbicide, control of *Setaria* spp. was improved over the grass herbicide alone.

Data from both locations indicate that the grass herbicide alone and tank mixtures of the grass and broadleaf herbicides were effective

Table 7. Grass and broadleaf weed control at two locations from mixtures of Betamix and sethoxydim.

Herbicide treatment	Rate		Redfield[a] Setaria spp.	Redfield[a] Wild buckwheat	Watertown[a] Setaria spp.	Watertown[a] Redroot pigweed	Watertown[a] Wild Mustard
	- (kg/ha) -		(%)				
Betamix + sethoxydim[b]	0	0	0 e	0 e	0 g	0 e	0 e
Betamix + sethoxydim	0.84	0	34 d	55 d	5 fg	32 cd	72 d
Betamix + sethoxydim	1.12	0	26 d	60 bcd	10 f	35 bcd	82 b
Betamix + sethoxydim	1.40	0	28 d	63 bcd	20 e	43 abc	85 b
Betamix + sethoxydim	0	0.28	87 ab	1 e	82 d	0 e	0 e
Betamix + sethoxydim	0.84	0.28	71 c	66 bcd	87 bcd	35 bcd	80 bc
Betamix + sethoxydim	1.12	0.28	81 bc	76 ab	89 abc	35 bcd	72 d
Betamix + sethoxydim	1.40	0.28	80 bc	86 a	83 cd	43 abc	83 b
Betamix + sethoxydim	0	0.43	94 a	6 e	85 cd	3 e	0 e
Betamix + sethoxydim	0.84	0.43	71 c	59 cd	93 ab	27 d	73 cd
Betamix + sethoxydim	1.12	0.43	86 ab	83 a	94 ab	45 ab	82 b
Betamix + sethoxydim	1.40	0.43	85 ab	74 abc	95 a	52 a	92 a

[a]Values within a column followed by the same letter are not significantly different at the 5% level.

[b]Treatments containing sethoxydim included crop oil concentrate at 1.25% (v/v).

Table 8. The type of interaction in Setaria spp. control with mixtures of Betamix and sethoxydim at Redfield.

Treatment		Observed	Expected	Response	
Herbicide	Rate	response	response[a]	difference	Interaction
	- (kg/ha) -	-----------	(%)	-------------	
Betamix	0	0			
Betamix	0.84	34			
Betamix	1.12	26			
Betamix	1.40	28			
Sethoxydim	0	0			
Sethoxydim[b]	0.28	87			
Sethoxydim	0.43	94			
Betamix + sethoxydim	0.84 + 0.28	71	91	-20	Antagonism
Betamix + sethoxydim	0.84 + 0.43	71	96	-25	Antagonism
Betamix + sethoxydim	1.12 + 0.28	81	90	- 9	Antagonism
Betamix + sethoxydim	1.12 + 0.43	86	96	-10	Antagonism
Betamix + sethoxydim	1.40 + 0.28	80	91	-11	Antagonism
Betamix + sethoxydim	1.40 + 0.43	85	96	-11	Antagonism

[a]Expected response of herbicide combinations based on Colby's calculation (8).

[b]Treatments containing sethoxydim included crop oil concentrate at 1.25% (v/v).

in controlling Setaria spp. However, antagonism occurred with tank mixtures at the Redfield location. Previous research has indicated antagonistic responses with sethoxydim and desmedipham combinations (31, 32, 46). Experimental differences may help explain the different responses in Setaria spp. control. Sunflowers at Redfield had to be replanted due to emergence difficulties from soil crusting in the spring. The emerged sunflowers were disced lightly before replanting, thus eliminating the initial weed flush. Postemergence herbicides at Redfield were applied at a much later date than at Watertown.

Wild buckwheat was the only consistent broadleaf weed present at the Redfield location (Table 7). Sethoxydim did not control wild buckwheat, but it appeared to increase control by Betamix. The crop oil concentrate applied with sethoxydim applications may be responsible for the slight control of wild buckwheat and possible enhancement of the broadleaf herbicides. Crop oil concentrate is known to cause slight toxicity of its own on some plant species. Betamix alone gave increased, but not significantly better, control as the rate was increased.

Redroot pigweed and wild mustard control were evaluated at the Watertown location (Table 7). Generally, sethoxydim did not provide any control of these broadleaf weeds. Control from Betamix was generally equal or slightly better when applied in combination with sethoxydim versus applied alone. The addition of the grass herbicide to the broadleaf herbicides seemed to enhance the toxicity of the broadleaf herbicides on redroot pigweed and wild mustard.

Dry weed weights were generally decreased with these herbicides (Table 9). Sampling the weed growth after treatment reflected the visual ratings of weed control. The Redfield location had drastic reductions in the amount of the weed growth when grass and broadleaf herbicides were tank mixed. The weed growth consisted mainly of _Setaria_ spp., and sethoxydim reduced the weight of the weeds 76 to 87% of the untreated control. Betamix also significantly reduced the weed growth by 53 to 62% when applied alone. Combinations of the two herbicides were most effective in reducing weed growth. All of the tank mixtures reduced the weed dry weights 90% or more.

Results of the weed dry weights from the Watertown location were more variable than the Redfield location (Table 9). The weed population mainly consisted of broadleaf species, such as redroot pigweed, wild mustard, prostrate pigweed (_Amaranthus graecizans_ L.) and common lambsquarters (_Chenopodium album_ L.). The broadleaf herbicides did not statistically decrease the weights of weeds from those collected for the weedy check. Rates of sethoxydim did not appear to reduce weed growth. In the combinations, increasing the rate of the broadleaf mixture tended to decrease the weed dry weights. Weed growth reduction was most prominant when 1.12 and 1.40 kg/ha of Betamix was combined with 0.43 kg/ha of sethoxydim, where 62 to 66% of the weed growth was reduced. The high concentration of adjuvants and the crop oil concentrate in the combinations must have enhanced the herbicide activity on the broadleaf weed species.

Injury to the sunflowers was determined 7 and 16 days after

Table 9. Effect of Betamix and sethoxydim mixtures on weed dry weights and sunflower injury at two locations.

			Weed dry weight[a]		Sunflower injury[a]	
Herbicide treatment	Rate		Redfield	Watertown	Redfield	Watertown
	- (kg/ha) -		-------- (g) --------		-------- (%) --------	
Betamix + sethoxydim[b]	0	0	21.1 a	7.7 ab	0 d	0 e
Betamix + sethoxydim	0.84	0	8.0 bc	6.1 abcd	20 c	25 d
Betamix + sethoxydim	1.12	0	10.0 b	4.7 abcd	23 bc	30 cd
Betamix + sethoxydim	1.40	0	9.3 bc	5.5 abcd	26 ab	37 bc
Betamix + sethoxydim	0	0.28	5.0 cd	6.9 abc	1 d	2 e
Betamix + sethoxydim	0.84	0.28	1.6 d	5.5 abcd	23 bc	35 bc
Betamix + sethoxydim	1.12	0.28	1.7 d	4.8 abcd	28 ab	37 bc
Betamix + sethoxydim	1.40	0.28	1.0 d	4.0 bcd	30 a	42 ab
Betamix + sethoxydim	0	0.43	2.7 d	8.4 a	4 d	3 e
Betamix + sethoxydim	0.84	0.43	2.1 d	5.9 abcd	23 bc	35 bc
Betamix + sethoxydim	1.12	0.43	1.3 d	2.6 d	28 ab	42 ab
Betamix + sethoxydim	1.40	0.43	1.3 d	2.9 cd	29 a	45 a

[a]Values within a column followed by the same letter are not significantly different at the 5% level.

[b]Treatments containing sethoxydim included crop oil concentrate at 1.25% (v/v).

herbicide treatment, respectively, for the Watertown and Redfield locations (Table 9). Injury symptoms were similar to previous descriptions in other studies. Slight injury occurred at both rates of sethoxydim at each location. Symptoms of injury were most obvious soon after treatment, and disappeared as the growing season progressed. More injury was detected at the time of evaluation at Watertown than at Redfield because of the earlier observation date after treatment at Watertown. At the Redfield location, the addition of sethoxydim to a particular rate of the broadleaf mixture did not significantly increase the injury over that of the broadleaf mixture alone. A greater range of injury at Watertown revealed more consistent increases in crop injury which gave more differences between rates of sethoxydim and rates of Betamix. Addition of sethoxydim at 0.43 kg/ha to the broadleaf mixture always increased crop injury in relation to the singular broadleaf mixture. The sethoxydim plus crop oil concentrate in the tank mixtures apparently increased the response of Betamix to sunflowers.

Sunflower heights were analyzed by rates of the grass herbicide and by rates of the broadleaf herbicides (Tables 10 and 11). Heights at the Redfield location were reduced by the application of Betamix (Table 10). This reduction was similar to that discussed in previous experiments. Averaging sunflower height over Betamix rates gave the average effect of each rate of sethoxydim. Sethoxydim also significantly reduced sunflower height. Either the sethoxydim or the crop oil concentrate or both were harming sunflowers in terms of height

Table 10. Effect of Betamix and sethoxydim on sunflower height at Redfield when averaged across each herbicide in 1982.

Rate (kg/ha)	Sunflower height(cm)[a] July 31	August 11	August 23
---------- Betamix ----------			
0.00	60 a	117 a	124 a
0.84	49 b	107 b	123 ab
1.12	46 bc	101 c	118 bc
1.40	42 c	96 c	116 c
---------- Sethoxydim[b] ----------			
0.00	53 x	111 x	126 x
0.28	46 y	102 y	118 y
0.43	49 xy	103 xy	117 y

[a]Values within a column and within a herbicide followed by the same letter are not significantly different at the 5% level.

[b]Crop oil concentrate at 1.25% (v/v) was included with sethoxydim treatments.

reduction. This pattern was true for all three measurements taken at the Redfield location.

Sunflower height as affected by rates of Betamix averaged across sethoxydim rates were significantly decreased by Betamix at Watertown (Table 11). Increasing herbicide rate further decreased sunflower height at the first two dates of measurement. Sethoxydim rates averaged across Betamix rates also reduced the height of the sunflowers. Significantly shorter sunflowers were evident from the 0.43 kg/ha rate of sethoxydim at the first three measurements. Sethoxydim is not known to affect the growth of broadleaf plant species, but the data in this study suggest a height reduction with its use on sunflowers. Sethoxydim applications with crop oil concentrate must exert some toxicity on sunflower plants.

Sunflower yield was not significantly affected by these herbicide treatments at either location, according to the analysis of variance. Yields of sunflowers were greater at Watertown than at Redfield (data not shown). This was due to the sunflower replanting at Redfield which then was susceptible to heavy seed weevil (Smicronyx fulvus (LeC.)) infestations. Yields at Redfield were quite variable due to large quantities of light seed caused by the seed weevil damage. Many of the lighter seeds were blown out of the combine, thus lowering yield.

Results of this study indicate that addition of sethoxydim to Betamix does not negatively affect broadleaf weed control, but may result in an antagonistic response in annual grass control. Generally,

Table 11. Effect of Betamix and sethoxydim on sunflower height at Watertown when averaged across each herbicide in 1982.

Rate (kg/ha)	Sunflower height(cm)[a] July 13	July 19	August 1	August 13
		Betamix		
0.00	44.8 a	70 a	115 a	117 a
0.84	29.2 b	46 b	100 b	110 b
1.12	28.7 bc	44 bc	99 b	109 b
1.40	27.4 c	42 c	95 b	108 b
		Sethoxydim[b]		
0.00	34.2 x	54 x	106 x	111 x
0.28	32.2 xy	50 xy	102 xy	112 x
0.43	31.2 y	47 y	99 y	111 x

[a]Values within a column and within a herbicide followed by the same letter are not significantly different at the 5% level.

[b]Crop oil concentrate at 1.25% (v/v) was included with sethoxydim treatments.

broadleaf weed control was slightly better when sethoxydim plus crop oil concentrate was added to Betamix applications than when Betamix was applied alone. Sethoxydim alone gave essentially no control of redroot pigweed, wild mustard, and wild buckwheat. The adjuvants in sethoxydim along with the crop oil concentrate apparently caused the slight increase in Betamix activity. Dexter (13) has observed increased broadleaf weed control with desmedipham and sethoxydim tank mixtures including oil concentrate as compared to the same treatments without oil. In this study, tank mixing the herbicides decreased weed dry weights more than using either type of herbicide alone. Visual injury to sunflowers was also enhanced by having sethoxydim in the herbicide treatment. The inclusion of crop oil concentrate in sethoxydim applications may have enhanced crop injury. Dexter (12, 13) reported more injury to sugarbeets with desmedipham and sethoxydim tank mixtures that included oil concentrate than those without oil. As expected, heights of the sunflowers were reduced by Betamix application. Sunflower heights were also decreased by sethoxydim application. The adjuvants and crop oil concentrate in the sethoxydim applications may also explain the height reduction by the singular sethoxydim treatments. Yields were not influenced by the application of these herbicide combinations. Greater broadleaf weed control, less weed dry weight, and greater crop injury occurred when sethoxydim was combined with Betamix than when these herbicides were singularly applied. The phytotoxicity of these herbicides may be enhanced when tank mixed together.

SUMMARY AND CONCLUSIONS

Desmedipham controlled wild mustard and redroot pigweed more effectively than phenmedipham in these studies. A synergistic interaction occurred with all tank mix combinations of the two herbicides for wild mustard control, except combinations containing 0.71 kg/ha of desmedipham. The magnitude of the synergism decreased as the rate of desmedipham was increased and increased as the rate of phenmedipham increased. Both herbicides caused injury symptoms of leaf necrosis and height reduction to sunflowers. Crop injury and sunflower heights were affected more by desmedipham than by phenmedipham. Injury effects were temporary and had no influence on sunflower yields.

Desmedipham and phenmedipham performance under various rainfall conditions was evaluated in field studies. The occurrence of 1 mm of rain immediately after herbicide application significantly decreased the control of redroot pigweed and wild mustard. Rainfall quantities as little as 0.25 mm effectively reduced injury symptoms on sunflower. Simulating a 12.7 mm rain at various time intervals after desmedipham and phenmedipham application was effective in reducing control of redroot pigweed and wild mustard. Improvement in redroot pigweed control occurred at a slow rate as the time interval prior to rain was increased, indicating slow uptake of the herbicides in redroot pigweed. A large portion of wild mustard control was achieved if rain did not occur within 2 h after herbicide application. Rain-free periods of about 18 h for redroot pigweed and 6 h for wild mustard were predicted for near-maximum performance of these herbicides. Sunflower injury occurred if rainfall was delayed until 18 h after herbicide application. This information is important when making spray decisions on how rainfall may affect herbicide performance.

Applying different amounts of water to sunflower plots prior to spraying with desmedipham and phenmedipham made no difference in the weed control or sunflower injury obtained in field studies. Better growing conditions through increased moisture levels did not enhance the activity of these herbicides on broadleaf weeds. Large weed size was the limiting factor prohibiting herbicide performance.

Antagonistic interactions in *Setaria* spp. control may occur when sethoxydim is tank mixed with Betamix, which is a commercial mixture of desmedipham and phenmedipham. Reduced control of *Setaria* spp. occurred at one of two locations. Broadleaf weed control was slightly better when sethoxydim and Betamix were combined than when Betamix was applied alone. Tank mixtures also increased sunflower injury. Sethoxydim with crop oil concentrate decreased the height of sunflower plants. The adjuvants in sethoxydim and the crop oil concentrate might explain the better weed control and higher crop injury. Sethoxydim has not been reported to affect broadleaf plant species, however, this study indicates that when used with crop oil concentrate a reduction in sunflower height occurs. These findings are helpful when considering tank mix aplications for broad spectrum weed control.

In conclusion, desmedipham applied alone appears to selectively control wild mustard in sunflowers. Crop injury at rates used in this study can be tolerated by sunflowers without yield reduction. Rainfall within a short time after herbicide application will severely reduce redroot pigweed control but not wild mustard control. A rainfall amount of 1 mm immediately after herbicide application is sufficient in reducing weed control of both plant species.

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